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Before the Federal Communications Commission
Washington DC 20554

In the Matter of
Advanced Television Systems
and Their Impact upon the
Existing Television Broadcast Service

MM Docket No. 87-268
Second Report and Order/Further Notice of Proposed Rule Making
8 May 1992

Informal Reply Comments of

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The opinions expressed herein are those of the author only.

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Executive Summary

Some commenters have objected to any consideration, at this time, of Orthogonal Frequency Division Multiplex and Single-Frequency Networks (OFDM and SFN) on many different grounds, including complexity and lack of testing. These objections are examined and seen to be without merit, particularly in view of the volume of work going on in Europe and the near-unanimity of European opinion that these methods have overwhelming advantages over the transmission technologies now advocated in the US.

Introduction

These informal reply comments are directed primarily to the reply comments of AT&T and Zenith, as well as the to the affidavit of Dr. Woo H. Paik of 13 July 1992, submitted with the Comments of General Instrument. Due to the author's absence, it was not possible to prepare this reply during the prescribed period, and, in any event, the Reply Comments of AT&T and Zenith only became available a few days ago.

AT&T and Zenith assert that no technologies other than employed in their system need to be considered, in particular Orthogonal Frequency Division Multiplex and Single-Frequency Networks. (OFDM and SFN) They rely on Dr. Paik's affidavit that OFDM is too complex for HDTV, and add a number of other potential disadvantages including:

- no new benefits
- OFDM is largely untested
- effects of transmitter nonlinearity
- cochannel and adjacent-channel interference unknown
- difficult to optimize for cable
- possible unknown inefficiencies
- guard bands might reduce efficiency
- SFN would require a totally new transmission plan
- SFN may require stations in a given locality to share antennas
- these technologies are "advocated by some who have no modulation/transmission system experience."

To the best of my knowledge and belief, all these concerns are groundless. Work on OFDM and SFN is being done under at least 6 different projects in Europe as well as at the Canadian Communications Centre, and a veritable blizzard of papers was presented recently at IBC and NAB. (See Appendix 1 for a list of these projects.) All these researchers without exception have concluded that these techniques are the best known for digital broadcasting.

It would be helpful to recognize that, until very recently, the field of digital terrestrial broadcasting has been *terra incognita* to almost everybody. There is still much to learn. At present, the volume of work being done outside the US on this subject substantially exceeds that being done domestically. As a result, the European researchers have accumulated far more experience with transmission than the US system proponents. While it is easy to understand why system proponents do not want to upset the selection process at this point, it would be quite foolish of the US to disregard the large volume of work being done in Europe and the apparent unanimity of European opinion on the best technical approaches.

Complexity of OFDM

The pertinent paragraph of Dr. Paik's affidavit is as follows:

"I have reviewed a proposed modulation approach known as Coded Orthogonal Frequency Division Multiplex (COFDM), and I believe that this approach is far too complex for use in a consumer television broadcasting system. The COFDM uses multiple low speed carriers to combat multipath and frequency selective fading. While the approach could be considered for digital audio broadcasting, the required complexity would become prohibitive for digital HDTV systems since it would require 500 or more 32-QAM modulated carriers to support the higher data rate requirements."

The complexity of OFDM is identical for audio and video, since it depends primarily on the total bandwidth. As already extensively field tested for audio, a full video channel with 256 or 512 carriers was in fact used for a multiplicity of audio signals. I have personally seen the video transmission equipment at NTL in Winchester, UK, and it is considerably smaller than the systems submitted to ATTC for testing. (Incidentally, OFDM is not a method for combating frequency-selective fading.)

The multiple carriers do not have to be individually generated. The entire transmitted signal is modulated and demodulated by a single Fourier transform operation comparable to the DCT already incorporated into the proponents' systems. (See Appendix 2 for an explanation of how this is done.) No guard bands are needed, since signals in adjacent channels are orthogonal. A much simpler channel equalizer is required with OFDM, so that there is some saving. In this connection, note that in the GI/MIT systems, the equalizer comprises 25% of all the special chips. Thus, OFDM is not more complex than currently proposed systems; it is about equally complex.

Spectrum Efficiency

As pointed out in my Comments of 15 July, the main motivation for using SFN is spectrum efficiency. In all liklihood, with SFN, the total number of channels that would have to be allocated to TV service to provide 20 different programs at each point in the country is 20, rather than 68 as at present. Currently proposed technology simply cannot do that; it would require at the very least 40 channels. In order to operate an SFN system, the receivers must be able to cope with "echoes" of 0 dB. Adaptive equalizers of known performance cannot do this, even without considering their effect on SNR. OFDM, on the other hand, constructively adds the echoes (whether they are moving or not) and not only can handle echoes of any amplitude, it also does not cause deterioration of the SNR.

The use of single-frequency networks (SFN) and the attendant very high spectrum efficiency, is therefore a unique benefit of OFDM.

With respect to a new frequency plan, there is going to be one anyway when the FCC takes back current NTSC channels after 15 years of simulcasting. Actually, SFN can be introduced channel by channel in any one area; it need never be used in areas where only a few stations are on the air. It permits guaranteed service in any selected geographical area, regardless of obstacles such as hills and buildings. Its total emitted power is much less than that of centralized transmitters. For a new broadcaster, installing SFN is probably cheaper than installing a conventional system, and, for everyone, the lower total transmitted power will result in on-going savings.

These matters are discussed in detail and the conclusions above are supported in a paper recently submitted to SS/WP1 by G. Chouinard of the Communications Research Centre in Ottawa.[1]

State of Testing of OFDM

In OFDM, as currently implemented, the source coder and channel coder are completely separated.[2] Therefore, the transmission tests already carried out in Europe and Canada in connection with digital audio broadcasting (DAB) are fully applicable to video. More such tests have been carried out than will have been carried out in the US by the time the proposed field testing will have been completed. Moreover, the principles of SFN have been field tested with OFDM, but will not be tested at all in the US under current plans. NTL, having already field tested their transmission system, intends a full video test this fall with an MPEG-type source coder.

Interference and Nonlinearity

OFDM can have a very high immunity to NTSC cochannel interference simply by not using the carriers that are close to the NTSC picture, color, and sound carriers, in a manner even better than the ATRC system. Adjacent-channel effects should be about the same as those of any other digital system. Nonlinearity should cause no special problems, as the beat frequencies are not any more likely to fall into other used channels. This makes the system usable on cable, although a system designed only for cable would undoubtedly be somewhat different.

Conclusion

The objections made so far to OFDM and SFN are seen to be without merit. These two transmission methods offer such overwhelming advantages over the methods now being advocated in the US that, at least, a thorough investigation is called for, as proposed in my Comments of 15 July 1992.

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[1]Gerald Chouinard, "Study on the Possibility of Using On-Channel Coverage Extenders in ATV Broadcasting," Government of Canada, Communications Research Centre, Ottawa, Ontario K2H 8S2, 7 July 1992.

[2]It should be understood that the author is simply bringing these developments to the attention of the Commission and other interested parties, and not necessarily advocating any particular system. In particular, for OFDM without SFN, he still advocates a soft threshold and hybrid transmission — techniques not now being applied in Europe. He is also considering the use of spread-spectrum methods together with joint source/channel coding.

Appendix 1 A List of European OFDM Projects.

• SPECTRE This comprises the work being done at the National Transcommunication Laboratories and the Independent Television Commission (descendants of the old Independent Broadcasting Authority) in Winchester, UK. In the spring of 1992, successful field tests were conducted of a system designed to deliver 12 Megabits/sec for CCIR 601 quality in an 8-MHz channel. Later in 1992, field tests including an MPEG-type source coder are planned.

• dTTb This project, Digital Television Terrestrial Broadcasting, is a consortium of the major electronics and broadcasting establishments in Europe, its members coming from France, UK, Italy, Germany, and the Netherlands. It plans to build on the work done in SPECTRE so as to develop a complete system, including HDTV. It has not yet been fully funded by the EC.

• HDTV-T This German consortium, comprising Bosch, DAB-Plattf., DLR/NT, DTB, FI/FTZ, Grundig, HHI, IRT, and ITT, plans to carry out a full program of research and development, leading to HDTV systems for DBS, cable, and terrestrial broadcasting. It is being led by the Heinrich Hertz Institute in Berlin.

• HD-DIVINE This is a Scandinavian consortium, including Swedish Telecom, Telecom Denmark, Norwegian Telecom and the Swedish Broadcasting Corporation. The intial work of the group led to a partially successful demonstration at the International Broadcasting Convention (IBC) meeting in Amsterdam in July 1992.

• Thomson CSF Some work is being done by Thomson CSF. It was first publicized at IBC 92, although a successful field test was held in the US in December 1990. It appears that this test was not disclosed for fear of undermining support for HD-MAC.

• STERNE This is the work going on at CCETT in Rennes. CCETT played an important role in the earlier DAB work, and is the source of the most significant theoretical study of OFDM.

Appendix 2 An excerpt from an HD-Devine Paper on implementation of OFDM.

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Development of a Prototype System for Digital Terrestrial HDTV

A prototype system for digital terrestrial HDTV has been developed within the Nordic project HD-DIVINE. In the following article, Erik Stare (project leader of this development project) describes the techniques used in the prototype system, for digital image coding and modulation, and the engineering trade-offs behind the system design.

Erik Stare, Telia Research AB

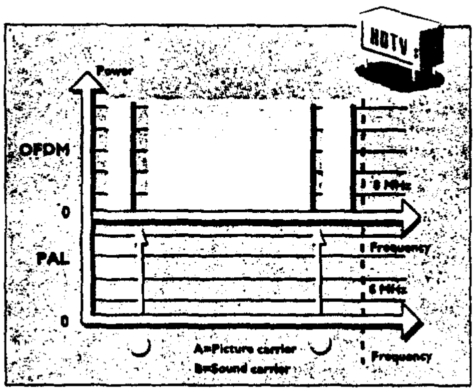

Fig. 6. The power of the PAL signal is concentrated largely in the picture and sound carriers. The OFDM signal can be made tolerant of interference from PAL transmissions if some of the OFDM carriers are not used.

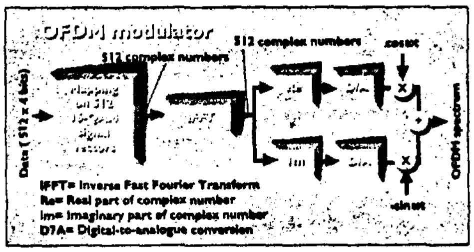

Fig. 7a. Block diagram of an OFDM modulator.

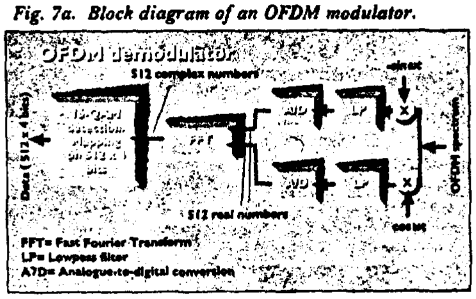

Fig. 7b. Block diagram of an OFDM demodulator.

Implementation of FFT

How can we modulate/demodulate a signal as complex as the COFDM signal? Do we need 448 separate oscillators, one for each carrier?

No, the signal can be directly modulated/demodulated very elegantly using digital signal processing; see Fig. 7. As mentioned above, the modem hardware incorporates no error protection (but the data entering the modulator is protected), for which reason modulation/demodulation is limited to OFDM.

The digital signal processing used is the Discrete Fourier Transform (DFT), implemented with the Fast Fourier Transform (FFT) algorithm. A complex OFDM spectrum is generated digitally, directly in the base band, from where it is transformed up to a suitable transmission frequency by multiplying the real component of the inverse FFT (I) after D/A conversion by cosωt and the imaginary component (Q) by -sinωt.

What we do on the transmitter side is, in principle, to first define a 512-point DFT spectrum, in which the nth complex point corresponds to the information of the nth carrier. For instance, if with QPSK on carrier 223 we wish to send the phase $\pi/4$, we assign to the 223rd DFT point the complex value $A \times e^{i\pi/4}$, where A is the constant amplitude.

The modem hardware, which is manufactured by the Norwegian company SINTEF DELAB, does not do exactly this. Instead, a 1024-point IFFT (inverse FFT) and an extra intermediate frequency of 8 MHz are used, to generate a complete analogue OFDM spectrum about this intermediate frequency. As the spectrum is generated entirely through digital signal processing, the phase difference between I and Q can be maintained at exactly 90 degrees, which is vital if they are not to interfere with each other.

Conclusions

Over the last year and a half of Phase 1, the Nordic HD-DIVINE project has developed a prototype system for digital terrestrial HDTV, comprising an HDTV image codec, which compresses an HDTV signal down to 24 Mbit/s, and a radio modem based on the COFDM principle.

The HDTV codec uses, eg a very advanced method for the estimation and compression of motion vectors, and is optimised especially for the very low data transmission speed of 24 Mbit/s. The radio modem was developed especially to tolerate terrestrial channel reflections and PAL interference.

At the time of writing, public demonstrations of digital terrestrial HDTV have only been held in the USA. With its prototype system, the HD-DIVINE project hopes to be the first to demonstrate digital terrestrial HDTV outside the USA, and the first in the world to use a modulation system based on COFDM in such a demonstration.